

CLAIMS

What is claimed is:

1. An optically-pumped mode-locked fiber ring laser for optical clock recovery of multiple wavelength division multiplexed optical signals for mode-locking a plurality of outputs of the laser as a plurality of recovered clocks for a plurality of the multiple wavelength division multiplexed optical signals, the laser comprising:
 - a laser cavity having a cavity length corresponding to an integer multiple of bit periods of at least one of the multiplexed optical signals for receiving a pre-amplified version of the plurality of wavelength division multiplexed optical signals to provide gain modulation through a phase-insensitive parametric amplification and recirculating a proportion of the output from the laser cavity back through the laser cavity for spatially mode-locking the output of the laser cavity as a recovered clock whereby the recovered optical clock each having a periodic train of optical pulses with a repetition rate corresponding to the clock rate of the corresponding multiplexed optical signal is generated by mode-locking of the optically-pumped laser produced by a spatial modulation of the phase-insensitive parametric gain produced by the pulsed nature of the wavelength division multiplexed optical signals;
 - a nonlinear gain medium disposed in the cavity, the medium having a sufficiently large dispersion at all of the wavelengths corresponding to the multiple wavelength multiplexed optical signals for minimizing four-wave mixing crosstalk among the multiple wavelength multiplexed optical signals, among the recovered clocks, and between the plurality of multiple wavelength multiplexed optical signals and the recovered clocks, the gain medium pumped by the plurality of pre-amplified multiplexed optical signals to provide efficient gain modulation through the phase-insensitive parametric amplification at a plurality of narrow wavelength bands, each of the plurality of narrow wavelength bands immediately adjacent to a wavelength of a corresponding optical signal and each of the plurality of narrow wavelength bands including a corresponding recovered optical clock

wavelength, and each of the corresponding optical signals copropagating in the laser cavity through the nonlinear gain medium with the recovered optical clocks;

an optical amplifier having an inhomogeneously broadened gain for amplifying the plurality of recovered clocks for compensating a portion of the cavity loss at all wavelengths of the plurality of recovered clocks; and

a wavelength selector for passing the light at the plurality of wavelengths of the recovered clocks for recirculation in the laser cavity and preventing the light from the multiple wavelength division multiplexed optical signals and a plurality of idler waves generated by four wave mixing between the multiple wavelength division multiplexed optical signals and recovered optical clocks from recirculating in the laser cavity.

2. The laser of claim 1, wherein the optical amplifier comprises a Raman amplifier.
3. The laser of claim 1, wherein the cavity is formed in an active mode-locking ring laser configuration.
4. The laser of claim 1, wherein the cavity is formed in a Sagnac laser configuration.
5. The laser of claim 1, wherein the wavelength selector comprises a narrow band filter.
6. The laser of claim 1, wherein the wavelength selector comprises at least one fiber Bragg grating.
7. The laser of claim 1, wherein the wavelength selector comprises a plurality of fiber Bragg gratings for adjusting the cavity length to correspond to an integer multiple of bit periods of at least one of the multiplexed signals.
8. The laser of claim 1, wherein the wavelength selector comprises an adjustable fiber delay line for adjusting the cavity length.

9. The laser of claim 8, wherein the adjustable fiber delay line is actively stabilised.
10. The laser of claim 1, wherein the nonlinear gain medium has an appropriate dispersion slope within the cavity such that a dispersion zero wavelength is shorter than the wavelength of any of the plurality of wavelength multiplexed optical signals or the wavelengths of the recovered clocks.
11. The laser of claim 1, wherein the coherence length of the plurality of wavelength division multiplexed optical signals is substantially greater than the cavity length.
12. The laser of claim 1, wherein the wavelength selector comprises an optical branch presenting a series of cascaded chirped fiber Bragg gratings, the optical branch being connected to the optical cavity by an optical circulator, whereby each chirped fiber Bragg grating minimizes a different idler wavelength in the cavity.
13. The laser of claim 12, wherein each chirped fiber Bragg grating is at least half as long as the physical spacing of two successive optical pulses of the plurality of wavelength division multiplexed optical signals in the cavity injected at the signal clock rate.
14. The laser of claim 1, wherein the optical amplifier comprises a Raman amplifier using the nonlinear medium of the gain modulation or another nonlinear medium as the gain medium for amplifying the plurality of the recovered clocks.
15. The laser of claim 1, wherein the wavelength selector has a free spectral range equal to the signal clock frequency or a subharmonic of the signal clock frequency for one of the plurality of wavelength division multiplexed optical signals.

16. The laser of claim 1, wherein the plurality of wavelength division multiplexed optical signals occupy respective channels separated from each other by a wavelength spacing, and the wavelength selector comprises a weak periodic filter with a free spectral range substantially equal to the wavelength spacing between adjacent channels.
17. The laser of claim 1, wherein the nonlinear medium comprises a dispersion-shifted fiber, a holey fiber or a photonic band gap fiber.
18. The laser of claim 14, further comprising:
 - an interleaver to couple the parametrically amplified plurality wavelength division multiplexed optical signals into the laser cavity while passing through the recovered clock signals for continued circulation in the cavity, the interleaver having the spectrally periodic design for combining odd and even numbered channels of the plurality of wavelength division multiplexed optical signals; and
 - a wavelength-independent coupler for splitting out a portion of light from the output of the laser to couple a corresponding plurality of recovered clocks out.
19. A method for recovery of a clock from each of a plurality of optically encoded wavelength multiplexed signals, the method comprising the steps of:
 - providing a phase-insensitive parametric actively mode-locked fiber ring laser including a cavity;
 - optical modulating a gain in the optical path of the optical cavity of the mode-locked laser;
 - applying a plurality of wavelength division multiplexed optically encoded input signals to the cavity; and
 - outputting a plurality of optical pulse streams from the cavity, wherein the gain is modulated in response to the plurality of wavelength division multiplexed optically encoded signals by modulating the spatial pattern of light in the laser cavity thereby locking the

spatial pattern of the output pulse stream to a timing wave of one of the optically encoded signals.

20. A system for recovery of a clock from each of a plurality of optically encoded wavelength multiplexed signals, the system comprising:

a phase-insensitive parametric actively mode-locked laser including a cavity;

an optically controlled optical modulator in the optical path of the optical cavity of the mode-locked laser;

means for applying an optically encoded input signal to the optically controlled optical modulator; and

means for outputting an optical pulse stream from the system;

wherein the optically controlled optical modulator in response to the optically encoded signal modulates the spatial pattern of light in the laser cavity thereby locking the spatial pattern of the output pulse stream to a timing wave of one of the optically encoded signals.